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Feedback Control Systems

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Published in:
Automatica

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1996

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):
Trentelman, H. L., & Trentelman, H. (1996). Feedback Control Systems. *Automatica*, 32(6).

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Feedback Control Systems*

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The third edition of the book *Feedback Control Systems* is a revised version of the first (1986) and second (1990) editions. The book contains an introduction to control theory for linear systems. The first main part of the book is meant as a text for a first course on control systems for advanced engineering students. Later chapters could be used for a more advanced course.

The main part of the book is concerned with what is usually called the *classical approach* to control. In this approach, models for systems (mostly first-, second- or higher-order linear differential equations obtained from first-principles modelling) are immediately put in their associated *transfer-function* form and represented by equations of the form

$$y = g(s)u,$$

where $g(s)$ is the transfer function of the system. In the classical approach (also often called the *frequency-domain approach*), the analysis of the control system, and the design of controllers is based on the properties of the underlying transfer function(s). The chapters dealing with the classical approach are all restricted to single-input/single-output systems.

In the second part of the book, an introduction is given to the *state-space approach* to linear control systems. Instead of representing system models by transfer functions, this approach is centered around the paradigm of representing the higher-order linear differential equation describing the system model by a model in *state-space form*:

$$\frac{dx}{dt}(t) = Ax(t) + bu(t), \quad (1)$$

$$y(t) = Cx(t) + du(t). \quad (2)$$

Different from the classical approach, which from the outset shifts from variable time t to variable frequency s , the state-space approach sticks to variable time: the state-space approach works within the *time domain*. Analysis and design of control systems in this approach take place by studying the associated matrices A , b , C and d .

Smaller parts of the book are concerned with the analysis and design of sampled-data control systems (also in the frequency domain), multivariable control systems and nonlinear control systems.

The book is extremely well laid out. Every chapter starts off with a clear introduction in which the issues to be addressed are described. At the end of each chapter, there is a section containing conclusions. The material in the book is illustrated by numerous pictures, plots and flow diagrams. In addition, the system properties and controller designs are illustrated by a large number of very nice physical examples. In my opinion, the author of the book has done a great job here: the examples are sufficiently simple to really illustrate the theory, but are hardly ever academic ('academic'

meaning that they illustrate the theory but have no physical meaning). In fact, at the beginning of the book, two entire chapters are devoted to the subject of deriving higher-order linear differential equations representing models for all kinds of physical systems. I was very pleased to see the models in the book being actually derived, instead of being put forward without further comment as so often occurs in textbooks on control. In later chapters, the models derived in these two introductory chapters are used to illustrate the theory.

I shall now give a more detailed description of the contents of the book. In the first chapter, a general introduction is given to control systems, including a discussion of the notion of open-loop and closed-loop control. Using a simple example, a discussion is given of the fundamental features of control system design. The chapter also introduces Laplace transforms and the concept of transfer function.

Chapter 2 consists of numerous examples of modelling mechanical, electrical thermal and fluid systems using higher-order, linear, constant-coefficient differential equations and their corresponding transfer functions. The approach to these examples is very nice: at the beginning of each subject area, first some elementary 'building blocks' are discussed. For example, in the treatment of thermal systems, first the building blocks 'thermal resistance' and 'thermal capacitance' are discussed. Next, these elementary building blocks are used to obtain models in a systematic manner. For example, in the discussion on thermal systems, the two aforementioned building blocks are used to model a process control system and a heating system.

Chapter 3 contains several examples of transfer function models of simple, physical, real-world control systems, like the ubiquitous water-level control system, a hydraulic servo-mechanism with a mechanical feedback, and a pneumatic pressure regulator. Also, a couple of examples from aerospace engineering (attitude control of satellites and spacecraft) are considered. The chapter also discusses system simulation using operational amplifiers, and the use of flow diagrams.

The fourth and fifth chapters deal with performance of feedback systems and the design of feedback controllers to improve the system's performance. An elementary discussion is given of the motivation for using feedback control. It is shown that feedback controllers are able to reduce the sensitivity of the system's performance to modelling uncertainty and exogenous disturbances, to reduce the steady-state error in the system's step response, and to improve the system's transient response. All this is illustrated by means of examples of first- and second-order systems. Using the example of the lightly damped harmonic oscillator, a discussion is given of features of the system's step response (overshoot, peak time, rise time and settling time) and the role these features play in the system's performance. Several control paradigms (PI, PD and PID) are discussed, and their limitations are explained.

Chapter 6 deals with the graphical technique of root locus in the analysis and design of control systems. Chapters 7 and 8 give an extensive discussion of the role of the system's frequency response in analyzing control systems and designing controllers. The graphical technique of polar plot is introduced and the Nyquist stability criterion is formulated. Also, a nice treatment is given of the graphical technique of the Bode plot. The relations between certain features of the Bode plot on the one hand and the performance criteria of gain and phase margin on the other are explained. In this

* *Feedback Control Systems*, 3rd ed., by John van de Vegte. Prentice-Hall, Englewood Cliffs, NJ (1994). ISBN 0-13-016379-1.

way, the system's performance is expressed in terms of properties of the system's Bode plot. This is used as a basis for controller design.

At this point in the book, the treatment of the classical approach to feedback control is finished. The subsequent Chapters 9 to 10 deal with the analysis and design of sampled-data control systems, all from a frequency-domain point of view. In chapters 11 and 12, the state-space approach to linear control systems is introduced. Chapter 11 starts with introducing the standard (SISO) state-space model that will be used. Furthermore, it contains a discussion of state trajectories, stability, controllability, observability and stabilizability. Chapter 12 deals with designing controllers, in particular controllers that achieve pole assignment and controllers that solve the so-called optimal regulator problem. This chapter also contains a discussion of dynamic observers. Chapter 13 deals with multivariable systems in the frequency domain (Nyquist array technique and Gershgorin bands). In Chapter 14, an introduction is given to nonlinear control systems (Popov and circle criteria). Finally, the book contains two appendices. In the first, some basic facts on vectors and matrices are collected. The second appendix contains a description of executable programs that can be found on the floppy disc accompanying the book. This disc contains programs to plot for a given system its unit step response, its root locus, its polar plot and its Bode plot.

As I already mentioned, the first edition of this book appeared in 1986. The core of the book is meant as an introductory treatment of the classical approach to control systems. More advanced material (on sampled-data systems, on the state-space approach, on multivariable systems and on nonlinear systems) is provided in later chapters. For an

introductory course—and even for a more advanced one—the book is really excellent. The presentation is very clear, and the concepts and ideas are illustrated extremely well by working them out for several interesting examples. However, undoubtedly because of its first appearing in 1986, the book hardly makes contact with more advanced ideas, concepts, techniques and results that have been developed well over the last 10 years. Here, I think of ideas on system uncertainty in terms of H_∞ error bounds, on the notion of robustly stabilizing a system, on quantifying the performance of a system in terms of the H_2 norm of certain closed-loop transfer functions, and on the use of weighting filters in order to achieve good performance over certain frequency ranges. In my opinion, it can very well be argued that some of these new ideas and concepts should not be omitted even from a first course on control systems, simply because they are so fundamental.

In conclusion, I think this book is very nice. It is very well suited to learn the classical basics on control, even outside a classroom. The book greatly benefits from the fact that it has gone through several updating rounds. Formulations and explanations are very clear, and the worked out examples are excellent. The book is clearly a product of great craftsmanship.

About the reviewer

Harry L. Trentelman was born in Voorst, The Netherlands in 1956. He has been Associate Professor of Systems and Control in the Department of Mathematics of the University of Groningen, The Netherlands since 1991. He is Associate Editor of the *SIAM Journal on Control and Optimization*. His Research interests are representation and control of linear systems.

Modeling of Dynamic Systems*

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This book deals with different approaches to model building for physical processes and systems. Model building of processes is one of the first stages of engineering work. Model building is an art in which the model builder utilizes all of his or her knowledge and experience to determine just one of many ways to solve a problem. This creative process has its own procedures, and this is the content of the book. The book is appropriate for all those for whom it was written, namely undergraduate students of all engineering faculties and people who are interested in model building in different areas of engineering, the natural sciences, and in economics and the social sciences as well.

The book has 360 pages, and is divided into four parts. The division of the material is natural. First, it is necessary to understand the different mathematical forms of models. There are two basic approaches to model building—analytical and experimental. The analytical approach, described in Part 2, uses physical laws to describe the behaviour of a dynamic system in mathematical form. The experimental approach, described in Part 3, uses measured data from the process to obtain a mathematical model of the

observed real plant. The last part of the book is dedicated to the utilization of mathematical models for system simulation and model validation. The parts of the book will now be described in a little more detail.

The first part, entitled 'Models', briefly describes the different types of models of dynamic systems. Input-output and state-space system descriptions, models of signals in the time and frequency domains, continuous- and discrete-time models, and discretization of continuous systems are also discussed briefly. Many examples are given here, and particular emphasis is given to the connections between different concepts. This part is not intended to cover in detail the different forms and properties of mathematical systems.

'Physical Modelling' is the second part of the book. This part describes how to construct a mathematical model from physical laws in electrical circuits, mechanical systems, flow systems and thermal systems. It is shown that there is an analogy between different physical systems, thus allowing the development of a systematic modelling procedure for a broad class of systems. This is done using bond graphs. I am convinced that the model builder must be a specialist in the appropriate area and that a good mathematical model of reality can only be created through the cooperation of the specialist and the system engineer. However, both must share the same language, and their knowledge must partly overlap in order to cooperate effectively. This is the aim of the book.

The third part, entitled 'Identification', shows how to use data for model building. Many estimating procedures are given: estimation of transient response in the time domain, frequency analysis and signal spectra estimation. Great emphasis is given to system parameter estimation, but only one-shot methods are presented. Problems from the field of design of identification experiments are also mentioned. In

* *Modeling of Dynamic Systems*, by Lennart Ljung and Torkel Glad. Prentice-Hall, Englewood Cliffs, NJ (1994). ISBN 0-13-597097-0.